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(71) Applicant: **GENERAL MOTORS CORPORATION**
General Motors Building 3044 West Grand
Boulevard
Detroit Michigan 48202(US)

(72) Inventor: **Creech, George Edward**
4906 Guthrie Drive
Indianapolis, IN 46241(US)
Inventor: **Barber, Michael Joe**
208 Painted Hills
Martinsville, IN 46151(US)

(74) Representative: **Haines, Arthur Donald et al**
Patent Section 1st Floor Gideon House 28
Chapel Street
Luton, Bedfordshire LU1 2SE(GB)

(54) **Method of forming platinum-silicon-enriched diffused aluminide coating on a superalloy substrate.**

(57) A platinum-silicon powder is electrophoretically deposited on a nickel- or cobalt-base superalloy substrate (12). The deposited powder is heated to form a transient liquid phase on the substrate (12) and to initiate diffusion of Pt and Si into the substrate (12). An aluminium-chromium powder is then electrophoretically deposited on the Pt-Si enriched substrate and diffusion heat-treated to form a corrosion- and oxidation-resistant Pt-Si-enriched diffused aluminide coating (14) on the substrate (12). The presence of both Pt and Si in the aluminide coating (14) unexpectedly improves coating ductility as compared to a Pt-enriched diffused aluminide coating without Si on the same substrate material.

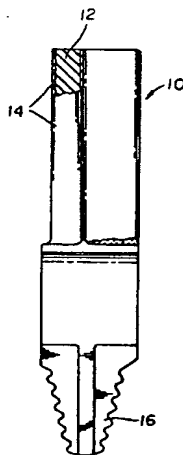


FIG. 1

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The invention relates to corrosion/oxidation-resistant platinum-silicon-enriched diffused aluminide coatings for nickel and cobalt base superalloys and to methods for their formation on such superalloys.

In the gas turbine engine industry, there continues to be a need for improved corrosion- and oxidation-resistant protective coatings for nickel-base and cobalt-base superalloy components, such as blades and vanes, operating in the turbine section of the gas turbine engine. The use of stronger superalloys that often have lower hot corrosion resistance, the desire to use lower grade fuels, the demand for longer life components that will increase the time between overhaul and the higher operating temperatures that exist or are proposed for updated derivative or new gas turbine engines underscore this continued need.

Diffused aluminide coatings have been used to protect superalloy components in the turbine section of gas turbine engines. In a typical example, an aluminide coating is formed by electrophoretically applying an aluminium-base powder to a superalloy substrate and heating to diffuse the aluminium into the substrate. Such coatings may include chromium or manganese to increase the hot corrosion/oxidation resistance thereof.

To this end, it is known to improve the hot corrosion/oxidation resistance of simple diffused aluminide coatings by incorporating a noble metal, especially platinum, therein. Such platinum-enriched diffused aluminide coatings are now applied commercially to superalloy components by first electroplating a thin film of platinum onto a carefully cleaned superalloy substrate, applying an activated aluminium-bearing coating on the electroplated platinum coating and then heating the coated substrate at a temperature and for a time sufficient to form the platinum-enriched diffused aluminide coating on the superalloy substrate. Optionally, the platinum may be diffused into the substrate either prior to or after the application of the aluminium. The platinum forms an aluminide of $PtAl_2$ and remains concentrated toward the outer surface regions of the coating.

Modified versions of the basic platinum-enriched diffused aluminide coating have been developed. One version on nickel-based alloys includes a two-phase microstructure of $NiAl(Pt)$ and $PtAl_2$. Another version uses a fused salt technique to deposit the platinum layer followed by a high activity-low temperature aluminizing treatment. This latter coating includes a thick Pt_2Al_3 plus $PtAl$ structured zone.

Platinum-enriched diffused aluminide coatings have been tested on nickel- and cobalt-base superalloys and have been found to exhibit better hot corrosion/oxidation resistance than the unmodified, simple diffused aluminide coatings on the same substrates. However, the platinum-enriched diffused aluminide coatings have exhibited reduction in coating ductility and undesirable increase in ductile-to-brittle transition temperature (DBTT) as compared to the unmodified, simple diffused aluminide coatings.

It has been proposed to improve the hot corrosion/oxidation resistance of diffused aluminide coatings by alloying the coating with silicon. In particular, the application of a high-purity silicon slurry spray followed by a pack aluminizing treatment has been reported to improve the hot corrosion/oxidation resistance of nickel-base superalloys. However, the addition of silicon to the diffused aluminide coating has also been reported to reduce the ductility of the coating.

It is an object of the present invention to provide a method for applying a hot corrosion- and oxidation-resistant platinum-silicon-enriched diffused aluminide coating to nickel- and cobalt-base superalloy substrates in such a manner as to reduce the overall cost of the coating application. It is another object of the present invention to increase the ductility of a platinum-enriched diffused aluminide coating at elevated temperatures without compromising hot corrosion and oxidation resistance by the inclusion of both platinum and silicon in the coating.

The present invention contemplates a method of forming a hot corrosion- and oxidation-resistant platinum-silicon-enriched diffused aluminide coating of improved ductility on a nickel- or cobalt-base superalloy substrate, comprising the steps of (a) electrophoretically depositing onto the substrate a platinum-silicon powder comprising about 3 percent to about 50 percent by weight silicon and the balance essentially platinum, (b) heating the deposited platinum-silicon powder at a temperature sufficient to melt the powder into a transient liquid phase in order to initiate diffusion of platinum and silicon into the substrate, (c) electrophoretically depositing an aluminium-bearing mixture or pre-alloyed powder onto the platinum and silicon-enriched substrate, and (d) heating the deposited aluminium-bearing powder at a temperature and for a time sufficient to form a platinum and silicon-enriched diffused aluminide coating which exhibits hot corrosion and oxidation resistance generally comparable to that of $MCrAlY$ overlay coatings and which also exhibits a surprising and unexpected improvement in coating ductility at elevated temperatures, such as $538^{\circ}C$ to $760^{\circ}C$ ($1000^{\circ}F$ to $1400^{\circ}F$), as compared to the ductility of conventionally-applied platinum-enriched diffused aluminide coatings without silicon formed on the same substrate material.

The present invention also contemplates a hot corrosion- and oxidation-resistant article comprising a nickel or cobalt superalloy substrate having a platinum and silicon-enriched diffused aluminide coating

formed thereon and exhibiting a coating ductility at elevated temperatures greater than a conventionally-applied platinum-enriched diffused aluminide coating (without silicon) on the same substrate material.

The invention and how it may be performed are hereinafter particularly described with reference to the accompanying drawings, in which:

- 5 Figure 1 is a schematic view (partly broken away and in section) of a typical turbine blade carrying a coating of a platinum-silicon-enriched diffused aluminide coating according to the present invention.
 Figure 2 is a photomicrograph at 500X magnification of a platinum-silicon-aluminide coating formed on a nickel-base (Mar-M247) superalloy substrate in accordance with the invention; and
 Figure 3 is a photomicrograph at 500X magnification of a platinum-silicon-aluminide coating formed on a
 10 cobalt-base (Mar-M509) superalloy substrate.

The coating method of the present invention is particularly suitable for nickel- and cobalt-base superalloy castings such as, e.g., the type used to make blades and vanes for the turbine section of a gas turbine engine. Figure 1 illustrates, for example, a turbine blade 10 formed of nickel- or cobalt-base superalloy body portion 12 provided with a diffused platinum-silicon-enriched aluminide coating layer 14 as described in this specification. For purposes of illustration, the thickness of coating layer 14 is exaggerated
 15 in Figure 1, the actual thickness being of the order of 30 to 100 micrometres (a few thousandths of an inch). It is usually unnecessary to provide the corrosion/oxidation-enriched coating layer of the present invention over a fastening portion 16 of the blade 10.

The method of the present invention involves producing a modified diffused aluminide coating
 20 containing platinum and silicon on nickel- or cobalt-base superalloy substrates by a sequential two-step electrophoretic deposition process with a diffusion heat treatment following each electrophoretic deposition step. Although not so limited, the method of the invention is especially useful in applying hot corrosion/oxidation-resistant platinum and silicon-enriched diffused aluminide coatings having increased coating ductility to components, such as blades and vanes, for use in the turbine section of gas turbine
 25 engines.

In a preferred embodiment of the invention, platinum and silicon are applied in the form of an alloy powder to the surface of a nickel- or cobalt-base superalloy substrate (e.g., nickel-base superalloys such as IN738, IN792, Mar-M246, Mar-M247, and cobalt-base superalloys such as Mar-M509, which are known to
 30 those in the art) by a first electrophoretic deposition step. The alloy powder is prepared by mixing finely-divided platinum powder with silicon powder of about one (1) micrometre particle size, compacting the mixed powders into a pellet and sintering the pellet in an argon atmosphere or other suitable protective atmosphere in a stepped heat treatment. One such heat treatment includes soaking (sintering) the pellet (1) at 760°C (1400°F) for 30 minutes, (2) at 816°C (1500°F) for 10 minutes, (3) at 830°C (1525°F) for 30 minutes, (4) at 982°C (1800°F) for 15 minutes and then (5) at 1038°C (1900°F) for 30 minutes. The
 35 sintered pellet is reduced to approximately 0.043 mm in size (-325 mesh size) by pulverizing in a steel cylinder and pestle and then ball-milling the pulverized particulate material in a fluid vehicle (60% by weight isopropanol and 40% by weight nitromethane) for 12 to 30 hours under an inert argon atmosphere to produce a platinum-silicon alloy powder typically in the 1 to 10 micrometre particle size range. Such alloy powder may also be produced by other suitable methods known in the art, such as gas atomization.

40 Silicon is included in the alloy powder (as a melting-point depressant) in an amount from about 3 percent to about 50 percent by weight silicon with the balance essentially platinum. A silicon content less than about 3 percent by weight is insufficient to provide an adequate amount of transient liquid phase in the subsequent diffusion heat treatment whereas a silicon content greater than about 50 percent by weight provides excessive transient liquid phase characterized by uneven coverage of the substrate. Preferably the
 45 platinum-silicon powder comprises about 5 to 20 percent by weight silicon and the balance essentially platinum. A particularly preferred alloy powder composition includes about 10 percent by weight silicon with the balance essentially platinum. Moreover, as will be explained hereinbelow, the presence of silicon in combination with platinum in the diffused aluminide coating of the invention has been found to unexpectedly improve coating ductility as compared to conventionally applied platinum-enriched diffused aluminide
 50 coatings without silicon.

The platinum-silicon alloy powder (10% by wt. Si - 90% by wt. Pt) is electrophoretically deposited on the nickel- or cobalt-base superalloy substrate after first de-greasing the substrate and then dry-honing (cleaning) the substrate using 220 or 240 grit aluminium oxide particles.

The electrophoretic deposition step is carried out in the following electrophoretic bath:

55 Electrophoretic Bath Composition

(a) solvent:

60 ± 5% by weight isopropanol

40 ± 5% by weight nitromethane

(b) alloy powder: 20-25 grams alloy powder/litre of solvent

(c) zein: 2.0-3.0 grams zein/litre of solvent

5 (d) cobalt nitrate hexahydrate (CNH): 0.10-0.20 grams CNH/litre of solvent

To effect electrophoretic deposition from the bath onto nickel- or cobalt-base superalloy substrates, the superalloy substrate is immersed in the electrophoretic bath and connected in a direct current electrical circuit as a cathode. A metallic strip (e.g., copper, stainless steel, nickel or other conductive material) is used as the anode and immersed in the bath adjacent the specimen (cathode). A current density of about 1-2 mA/cm² is applied between the substrate (cathode) and the anode for 1 to 3 minutes with the bath at room temperature. During this time, the platinum-silicon alloy powder coating is deposited as a uniform-thickness alloy powder deposit on the substrate. The weight of the coating deposited is typically about 10-20 mg/cm² of substrate surface, although coating weights from about 8 to 30 mg/cm² are suitable.

The coated substrate is then removed from the electrophoretic bath and air-dried to evaporate any residual solvent.

The dried, coated substrate is then subjected to a diffusion heat treatment in a hydrogen, argon, vacuum or other suitable protective atmosphere furnace at a temperature of about 1093°C (2000°F) for about 8 to about 30 minutes for nickel-base superalloy substrates or at a temperature of about 1038°C (1900°F) for about 30 to 60 minutes for cobalt-base superalloy substrates. Following the diffusion heat treatment, the coated substrate is cooled to room temperature.

The temperature and time of the diffusion heat treatment are selected to melt the deposited platinum-silicon alloy powder coating and form a transient liquid phase evenly and uniformly covering the substrate surface to enable both platinum and silicon to diffuse into the substrate. Typically, the platinum-silicon-enriched diffusion zone on the substrate is about 25.4 to 57.2 micrometres (1 to 1.5 mils) in thickness and includes platinum and silicon primarily in solid solution in the diffusion zone.

As mentioned hereinabove, the composition of the platinum-silicon alloy powder (preferably 90% by weight Pt - 10% by weight Si) is selected to provide an optimum transient liquid phase for diffusion of platinum and silicon into the substrate during the first diffusion heat treatment.

Following the first diffusion heat treatment, the platinum-silicon-enriched superalloy substrate is cleaned by dry-honing lightly with 220 or 240 grit aluminium oxide particulate material.

After cleaning, the platinum-silicon-enriched superalloy substrate is coated with an aluminium-bearing powder deposited by a second electrophoretic deposition step. Preferably the aluminium content of the aluminium-bearing powder is about 40 percent to about 75 percent by weight, with the balance of the powder being chromium and, optionally, manganese. Preferably, for nickel-base superalloy substrates, a pre-alloyed powder comprising, e.g., either (1) 55% by weight aluminium and 45% by weight chromium or (2) 50% by weight aluminium, 35% by weight chromium and 15% by weight manganese is electrophoretically deposited on the substrate. For cobalt superalloy substrates, a pre-alloyed powder comprising, e.g., either (1) 65% by weight aluminium and 35% by weight chromium or (2) 70% by weight aluminium and 30% by weight chromium is preferably electrophoretically deposited on the substrate.

The electrophoretic deposition step is carried out under the same conditions set forth hereinabove for depositing the platinum-silicon alloy powder with, however, the aluminium-bearing powder substituted for the platinum-silicon alloy powder in the electrophoretic bath. The same quantity (e.g., 20-25 grams of aluminium-bearing alloy powder) is employed per litre of solvent to electrophoretically deposit the aluminium-bearing alloy powder onto the substrate.

The aluminium-bearing powder coating is electrophoretically deposited with coating weights in the range of about 15 to about 40 mg/cm² regardless of the composition of the aluminium-bearing coating and the composition of the substrate.

After the aluminium-bearing powder coating is electrophoretically deposited, the coated substrate is air-dried to evaporate residual solvent.

Thereafter, the dried, aluminium-bearing powder coated substrate is subjected to a second diffusion heat treatment in a hydrogen, argon, vacuum or other suitable atmosphere furnace to form a platinum and silicon-enriched diffused aluminide coating on the substrate. For nickel-base superalloy substrates, the second diffusion heat treatment is carried out at about 1079°C to 1149°C (1975°F to 2100°F) for about 2 to 4 hours. For cobalt-base superalloy substrates, the second diffusion heat treatment is conducted at a temperature of about 1038°C (1900°F) for about 2 to 5 hours.

The diffused aluminide coating formed by the second diffusion heat treatment typically is about 50.8 to 88.9 micrometres (2 to 3.5 mils) in thickness and typically includes a two-phase platinum-rich outer zone as illustrated in Figure 2 which comprises a photomicrograph of a Mar-M247 substrate 18 having a Pt-Si

enriched diffused aluminide coating 20 formed thereon by the method of the invention (e.g., deposit 90% by weight Pt: 10% by weight Si/ diffuse 1093 °C (2000 °F) for 30 minutes/ deposit 55% by weight Al:45% by weight Cr/ diffuse 1093 °C (2000 °F) for 2 hours). Numerals 22 and 24 respectively identify a nickel plate layer and a Bakelite layer used in the metallographic preparation of the sample for the photograph. The platinum content of the diffused aluminide coating produced in accordance with the invention is typically in the range from about 15 to about 35% by weight adjacent the outer surface of the coated substrate (i.e., about the same as conventionally applied Pt-enriched diffused aluminide coatings). The silicon content of the coating of the invention is typically in the range from about 0.5 to about 10% by weight adjacent the outer surface of the coated substrate.

Figure 3 is a photomicrograph of a Mar-M509 cobalt-based substrate 28 having a platinum-silicon-enriched diffused aluminide coating 30 formed by the method of this invention. Numerals 32 and 34 respectively identify nickel and Bakelite metallographic layers as described with respect to Figure 2.

To illustrate the effectiveness of the invention in providing a hot corrosion- and oxidation-resistant diffused aluminide coating, 16 samples of Mar-M247 nickel-base superalloy in the form of 3.15 mm (1/8 inch) diameter pins were coated in the manner set forth hereinabove to form a platinum- and silicon-enriched diffused aluminide coating thereon. Four groups of four samples each were prepared to represent four variations of the present invention and were tested for hot corrosion and oxidation resistance. The four groups of samples were made as follows:

Group A - deposit 90% by weight Pt:10% by weight Si (28-29 mg/cm²)/ diffuse 1093 °C (2000 °F) for 30 mins./ deposit 55% by weight Al:45% by weight Cr/ diffuse 1093 °C (2000 °F) for 2 hrs./ coating thickness = 86.4 micrometres (3.4 mils).

Group B - deposit 90% by weight Pt:10% by weight Si (8.5-15.5 mg/cm²)/ diffuse 1093 °C (2000 °F) for 30 mins./ deposit 55% by weight Al:45% by weight Cr/ diffuse 1093 °C (2000 °F) for 2 hrs./ coating thickness = 73.7 micrometres (2.9 mils).

Group C - deposit 90% by weight Pt:10% by weight Si:(18-21 mg/cm²)/ diffuse 1093 °C (2000 °F) for 8 mins./ deposit 55% by weight Al:45% by weight Cr/ diffuse 1093 °C (2000 °F) for 2 hrs./ coating thickness = 71.1 micrometres (2.8 mils).

Group D - deposit 90% by weight Pt:10% by weight Si:(14-18 mg/cm²)/ diffuse 1093 °C (2000 °F) for 30 mins./ deposit 50% by weight Al:35% by weight Cr:15% by weight Mn/ diffuse 1093 °C (2000 °F) for 2 hrs./ coating thickness = 61.0 micrometres (2.4 mils).

All four groups of coated samples exhibited enhanced hot corrosion resistance in a low velocity, atmospheric burner rig test designed to duplicate the known Type I corrosion test (high temperature, hot corrosion conditions). The test was performed at 899 °C (1650 °F) with No. 2 diesel fuel doped with 1 percent by weight sulphur. ASTM grade synthetic sea salt solution (10 ppm) was ingested into the combustion zone to produce an especially aggressive corrosive environment. In this test, all four groups of samples made in accordance with this invention exhibited at least four to six times the coating life of a simple, unmodified aluminide-coated Mar-M247 sample (coating thickness of 45.7 micrometres (1.8 mils)) when compared on an hours per 25.4 micrometres (hours per mil) coating thickness basis. Moreover, this test suggested a coating life for the coated samples of the invention comparable to that of the more expensive CoCrAlY(26% by weight Cr-9% by weight Al) overlay coating (coating thickness of 73.7 micrometres (2.9 mils) which were also tested on the same substrate material (Mar-M247). For example, the typical corrosion penetration depth of the coating formed in accordance with the invention after 1000 hours in the test was comparable to that experienced by a vendor-produced CoCrAlY overlay coating (coating thickness of 73.7 micrometres (2.9 mils) on the same substrate material. Also, the coating life of the four groups of samples of the invention was comparable to that of a conventionally applied (Pt electroplate/ aluminized) platinum-enriched diffused aluminide coating (coating thickness of 76.2 micrometres (3.0 mils)) on the same substrate material.

Static oxidation testing at 982 °C, 1093 °C and 1177 °C (1800 °F, 2000 °F and 2150 °F) for up to 1000 hours in air of additional samples of the invention (e.g., deposit 90% by weight Pt:10% by weight Si:(24-29 mg/cm²)/ diffuse 1093 °C (2000 °F) for 30 mins./ deposit 55% by weight Al:45% by weight Cr/ diffuse 1093 °C (2000 °F) for 2 hrs/ coating thickness = 68.6 micrometres (2.7 mils)) was conducted. These samples exhibited oxidation resistance approximately equivalent to that of a conventional platinum-enriched diffused aluminide-coated sample (coating thickness of 68.6 micrometres (2.7 mils) tested on the same substrate material (Mar-M247) and approximately equivalent to that of the aforementioned CoCrAlY overlay coated sample (coating thickness of 78.7 micrometres (3.1 mils)) tested on the same substrate material. The coatings of the invention exhibited better diffusional stability in the oxidation tests than the CoCrAlY overlay coating.

Coating ductility tests were also conducted. These tests were conducted on a standard tensile test

machine with acoustic monitoring of strain-to-first cracking of the coating. Fluorescent penetrant inspection was used to verify coating cracks. The higher the percent elongation to produce a coating crack, the more ductile the coating is at that temperature. For the test data presented below in Table I, the 1 to 2 percent elongation values indicate that the coating has begun to deform more or less at the same rate as the substrate. The temperature at which this occurs is designated the ductile-to-brittle transition temperature (DBTT).

Table I

Coating/Alloy	Strain-to-first crack (%) as a Function of Temperature °C (°F)			
	Temperature °C (°F)			
	538 (1000)	649 (1200)	760 (1400)	871 (1600)
1. Simple aluminide/ IN 738	0.40	0.55	1.26	>2.1
2. Silicon-aluminide/ IN 738	0.31	0.32	0.58	>2.0
3. Silicon-aluminide/ Mar-M247	0.23	0.42	0.52	>1.3
4. Platinum-aluminide/ Mar-M247	0.34	0.31	0.54	>1.5
5. Pt-silicon-aluminide/ Mar-M247*	0.51	0.50	0.72	>1.5

* Group B described above

The first two lines of data for samples No.1 and No.2 in Table I show the expected decrease in ductility as a result of the addition of silicon to a simple, unmodified diffused aluminide coating. These lines also show a somewhat higher DBTT for sample No.2 as compared to sample No.1, indicating that sample No.2 (silicon-modified aluminide) becomes ductile only at a somewhat higher temperature. A similar ductility (line 3 in Table I) was observed for a silicon-aluminide coating on Mar-M247.

The decrease in ductility resulting from the addition of platinum to a simple diffused aluminide coating is especially evident from the data developed at 649 °C (1200 °F) and 760 °C (1400 °F). Sample No.4 (Pt-aluminide) shows a decrease in ductility as compared to that of sample No.1.

Sample No.5 (made in accordance with the invention) shows an unexpected, significant improvement in coating ductility as compared to samples No.2, No.3 and No.4. Since improvements in coating ductility on the order of 0.2 percent translate to enhanced stress bearing capability as well as enhanced thermal cycling capability of the coating, the improvement in coating ductility exhibited by sample No.5 relative to samples No.2, No.3 and No.4 is significant in a practical sense for improving performance of the coating in service. Moreover, this improvement in coating ductility of sample No.5 is achieved in combination with the excellent hot corrosion/oxidation resistance demonstrated previously hereinabove.

The relative changes in coating ductility due to the addition of platinum and silicon individually and together to a simple diffused aluminide coating can be further illustrated as follows:

Table II

Effect of Coating Additions on Coating Ductility

5

Change in Ductility (%)

10	<u>Change in Coating Composition</u>	<u>538°C (1000°F)</u>	<u>649°C (1200°F)</u>	<u>760°C (1400°F)</u>
	Addition of silicon to aluminide			
	IN738 Substrate	-22.5	-41.8	-54.0
15	Mar-M247 Substrate	-42.5	-23.6	-58.7
	Addition of platinum to aluminide			
	Mar-M247	-15.0	-43.6	-57.1
20	Addition of silicon to platinum-aluminide			
	Mar-M247	+50.0	+38.0	+33.3

25

The method of the invention thus provides a platinum- and silicon-enriched diffused aluminide-coated superalloy substrate that not only exhibits excellent hot corrosion/oxidation resistance comparable to that of CoCrAlY overlay coatings and conventionally applied platinum- or silicon-enriched diffused aluminide coatings but also exhibits an unexpected and surprising improvement in elevated temperature coating ductility compared to conventional platinum- or silicon-enriched diffused aluminide coatings as a result of the presence of both platinum and silicon in the coating. Moreover, the method of the invention achieves these advantageous results using a process and equipment with lower cost than processes and methods used to apply CoCrAlY overlay coatings. Moreover, these advantageous results are achieved without the need for an electroplating step to deposit platinum on the substrate as heretofore used in processes to form platinum-enriched diffused aluminide coatings on superalloys. Using an electrophoretic deposition step to deposit platinum and silicon alloy powder initially on the superalloy substrate instead of an electroplating step to deposit only platinum provides numerous advantages such as the following: (1) less substrate surface preparation is required for the electrophoretic deposition step, (2) the time to effect electrophoretic deposition is less, (3) no strong acids, no corrosive vapors and no bath heating are present or required for the electrophoretic deposition step, (4) the electrophoretic bath is less sensitive to contamination by metallic ions as well as organic materials, (5) simpler, less costly anode materials are usable for the electrophoretic deposition step, (6) more uniform, self-levelling deposits are achievable with the electrophoretic step, (7) the Pt-Si alloy powder remaining in the electrophoretic bath can be re-used after removal of spent solvent, washing the powder and replenishing the bath with fresh solvent, (8) the deposition of the Pt-Si alloy powder and the aluminium-bearing powder on the substrate are conducted on the same type of equipment without the need for separate plating facilities (9) simple, cheap rubber masks can be used in the electrophoretic bath, and (10) no pH adjustment of the electrophoretic bath is necessary. These and other advantages of the electrophoretic deposition step provide significant cost savings in the formation of platinum-silicon enriched diffused aluminide coatings on superalloy substrates in accordance with the method of the invention.

Although the invention has been described in terms of certain specific embodiments, it is to be understood that modifications and changes can be made thereto within the scope of the invention as defined in the appended claims.

55 **Claims**

1. A method of forming a diffused aluminide coating (14) containing platinum on a nickel- or cobalt-base superalloy substrate body (12), said aluminide coating (14) having hot corrosion- and oxidation-resistant

properties, characterised in that said method comprises:

- (a) electrophoretically depositing onto said substrate body (12) a platinum-silicon powder comprising from about 3 percent to about 50 percent by weight silicon and the balance essentially platinum,
 - (b) heating the deposited platinum-silicon powder at a temperature sufficient to melt the powder into a transient liquid phase and to initiate diffusion of platinum and silicon into the substrate body (12),
 - (c) electrophoretically depositing an aluminium-bearing powder comprising aluminium, chromium and optionally manganese onto the platinum and silicon-enriched substrate body, and
 - (d) heating the deposited aluminium-bearing powder at a temperature and for a time sufficient to form a platinum- and silicon-enriched diffused aluminide coating (14) of improved ductility on the substrate body (12), which coating (14) has a coating ductility at elevated temperatures which is greater than the coating ductility of a platinum-enriched aluminide coating without silicon formed on the same substrate material.
2. A method according to claim 1, in which the platinum-silicon powder and/or the aluminium-bearing powder are pre-alloyed powders.
3. A method according to claim 1, in which the platinum-silicon powder comprises about 5 to 20 percent by weight silicon and the balance essentially platinum.
4. A method according to claim 1, in which the aluminium content of the aluminium-bearing powder is about 40 percent to about 75 percent by weight with the balance of the powder being chromium and optionally manganese.
5. An article (10) having hot corrosion- and oxidation-resistant properties, said article (10) comprising a nickel or cobalt superalloy substrate (12) having a platinum- and silicon-enriched diffused aluminide coating (14) formed thereon, said coating (14) having a coating ductility at elevated temperatures which is greater than the coating ductility of a platinum-enriched diffused aluminide coating without silicon formed on the same substrate material.

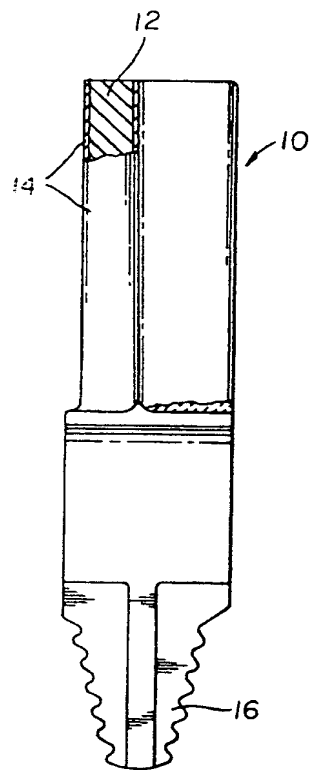


FIG. 1

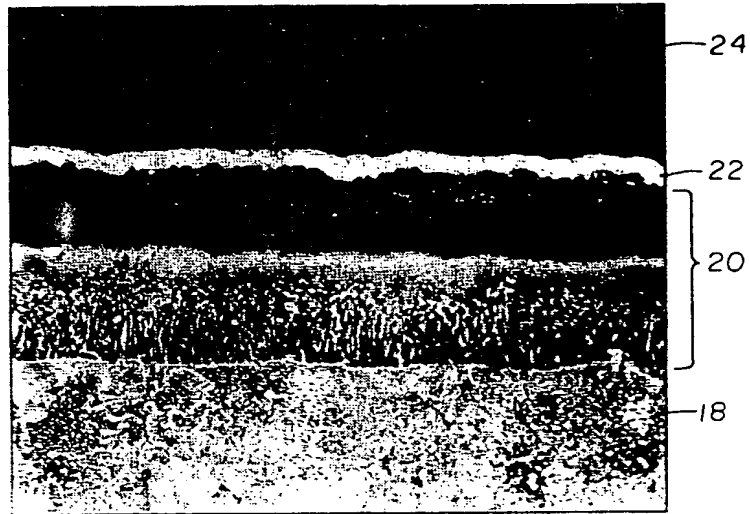


FIG. 2

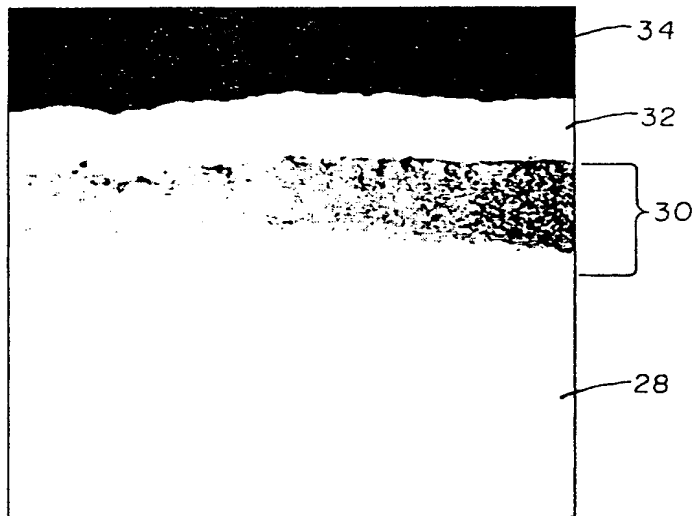


FIG. 3



European Patent
Office

EUROPEAN SEARCH REPORT

Application Number

DOCUMENTS CONSIDERED TO BE RELEVANT			EP 91203171.3
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	<u>US - A - 3 819 338</u> (KARL BUNGARDT et al.) * Abstract; claim 1 * --	1-5	C 23 C 24/00 C 23 C 10/00 C 25 D 13/02 B 32 B 15/00
A	<u>US - A - 3 955 935</u> (QUENTIN O. SHOCKLEY et al.) * Abstract; claims 1-4 * --	1-5	
A	<u>US - A - 4 439 470</u> (GEORGE K. SIEVERS) * Abstract * --	1-5	
A	<u>US - A - 4 530 885</u> (JAMES E. RESTALL) * Abstract; claims 1-8 * ----	1-5	
			TECHNICAL FIELDS SEARCHED (Int. Cl.5)
			C 23 C C 25 D B 32 D
The present search report has been drawn up for all claims			
Place of search VIENNA		Date of completion of the search 13-02-1992	Examiner HAUK
CATEGORY OF CITED DOCUMENTS			
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons d : member of the same patent family, corresponding document	